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Micro-siting wind resource assessment and near Shore wind farm analysis in Pakpanang district, Nakhon Si Thammarat province, Thailand

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Abstract

This paper presents the micro-siting wind resource assessment and near shore wind farm analysis in Pakpanang district, Nakhon Si Thammarat province, southern Thailand. One year of observed wind speed and wind direction data from a 120 m met tower installed near the shoreline are analyzed in order to investigate the monthly mean wind speeds and dominant wind directions at the site. The observed wind data is used to develop a 20 m resolution microscale map of the study area in order to analyze several configurations of near shore wind farms in the range of 10 to 90 MW. To this end, annual energy productions (AEP), wake effects, and theoretical capacity factors (TCF) are estimated using WAsP. Results show that the monthly mean wind speeds at 120 m above ground level are in the range of 3.3 to 5.3 m/s. The dominant wind at the site are from the NEE and SSW directions. In terms of the near shore wind farm analysis, the maximum net AEP is approximately 170 GWh/year (90 MW wind farm scenario), while the corresponding wind farm's wake loss is 3.65%, which corresponds to a 21.3% wind farm TCF.

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Keywords: Wind Energy, Wind Flow Modeling, Wind Farm, Capacity Factor, Wake Effect

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1. Introduction

Global warming and climate change are nowadays significant challenges for humankind. It is widely and generally accepted that the increase of greenhouse gases emissions (GHGs) in the atmosphere are caused by anthropogenic effects especially in modernized and industrialized countries. In regards to energy generation, industrialized countries produce about 65% of their electricity from fossil fuels based sources [1]. Based on current estimations, if developing countries continue their current levels of economic growth in the next few decades, they will consume 50% of the world's electricity demand by 2030 [1]. If these developing countries generate electricity similarly as today's modernized and industrialized countries, a dramatic rise in global GHGs emissions could certainly be expected. Consequently, cleaner energy generation is needed in order to reduce global GHGs emissions, notably to reduce CO2 emissions down to 450 ppm [2].

Recently, the development of renewable energy in order to replace fossil fuel energy generation has been identified as a key strategy in mitigating climate change and is now a standard objective of national and international climate and energy policies. Furthermore, the increase use of renewable energy not only enhances the mitigation of global warming but also serves to meet future energy demand [3].

At the present time, the global share of energy generation based on renewable energy sources in the mix of energy generation is growing fast. For its part, global wind energy capacity has been growing rapidly over the last few years. According to the Intergovernmental Panel on Climate Change (IPCC), 80% of the world's energy supply could be produced by renewable energy sources by 2050 and wind energy will play a major role in electricity generation in 2050 [4]. This is mainly due to economic, social and political factors, such as high and growing prices of traditional fossil fuels, a growing social environmental concern and governmental financial support of renewable energy development, e.g., feed-in tariffs (FIT), BOI tax exemption in Thailand or Kyoto protocol, and E.U. White Book in the world context [5]. The successful deployment of wind energy for energy generation in Europe (Denmark, Germany, U.K., etc.) and in North America (U.S.A. and Canada) has encouraged other countries to consider wind energy also in their respective electricity generation portfolios.

In order to catalyze the development of wind energy projects in developing countries, several in-depth wind research assessment research projects have been conducted [7].

For its part, the country of Thailand has a rapidly developing economy where the national peak energy demand in 2012 was 26,121 MW. The scope of the present Thai government policies and the variations in the current economic situation induces changes and fluctuations in both power demand and power supply predictions. Therefore, to have clear vision on power supply acquiring, a Thailand Power Development Plan 2010 – 2030 was developed and revised (PDP2010: Revision 3). The plan identifies crucial issues for energy supply and security in Thailand, i.e., results from a forecasted power demand study, the development of an integrated alternative energy master plan which seeks a national target of renewable energy and alternative energy penetration of 25% by 2021, and objectives related diversifying power reserve margin levels in order to increase the country's energy supply security [8].

In order to satisfy the country's renewable energy national target, it is estimated that approximately 1,775 MW of wind energy will need to be develop in Thailand by 2021. In order to guide the development of wind energy in Thailand and to identify potential sites for both onshore and offshore wind farms, several wind resource projects are being pursued [9-14]. To this end, the main objective of this paper is to present the wind resource assessment and micro-siting of a potential wind energy project in Pakpanang district, Nakhon Si Thammarat province, in southern Thailand.10 pt) Here introduce the paper, and put a nomenclature if necessary, in a box with the same font size as the rest of the paper. The paragraphs continue from here and are only separated by headings, subheadings, images and formulae. The section headings are arranged by numbers, bold and 10 pt. Here follows further instructions for authors.

2. Methodology

2.1. Study Are

Pakpanang district is a coastal district in Nakhon Si Thammarat province, Thailand, where the Talumphuk Cape is located. For its part, a 120 m stand-alone met tower is located at Pakpanang district in Nakhon Si Thammarat province, as is shown in Fig. 1.

For its part, the topography of Pakpanang district is quite plain and classified as flat terrain. The difference between the highest point and the lowest point based on Digital Elevation Model (DEM) obtained from the Royal Thai Survey Department is 2 m as shown in Fig. 2. For its part, most of the land use is composed of rice fields, shrimp farms, mangroves, and some urban areas. The roughness height based on the land use interpretation of the THEOS satellite image obtained in 2009 is shown in Fig. 3. The roughness height in the vicinity of the met tower is in the range of 0.01-1.6.

Since a large portion of the proposed study area (more than 30%) is composed of a water body, i.e., the Gulf of Thailand, and since the topography and roughness heights are generally uniform across the proposed study area, , in this work, the study area is extended 15 km around the met tower. In a previous study, it was shown, that wind flow modeling based on linear Jackson-Hunt model, such as the WAsP model used in this study, gives acceptable results in similar geographic and topographic situations [16].

Fig. 1. Geographical location of area study.

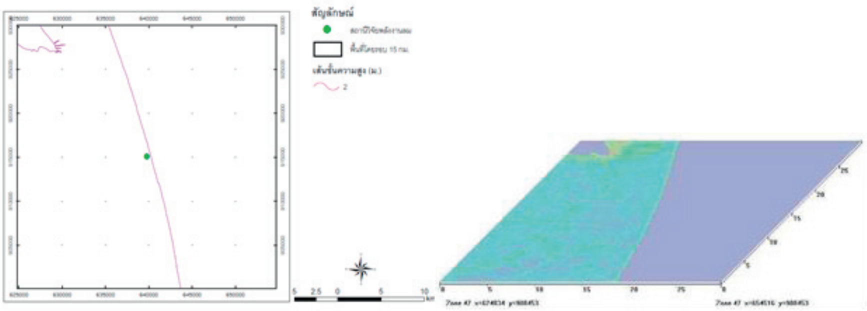

Fig. 2. 2-D and 3-D topography within 15 km around met tower.

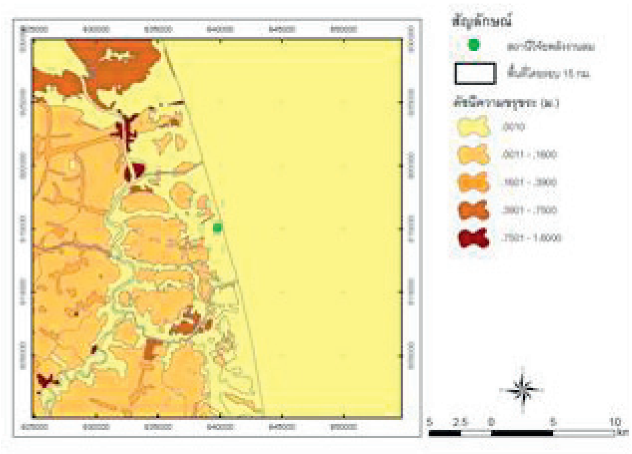

Fig. 3. Roughness height around the met tower.

2.2. Met Tower

In this study, wind energy data is taken from a stand-alone 120 m met tower installed at Pakpanang district in Nakhon Si Thammarat province, Thailand. The dataset consists of wind speeds, wind direction, as well as air temperature, relative humidity and atmospheric pressure for a one year period. Wind speeds are measured at 120 m, 110 m, 100 m, 90 m, 80 m, 70 m, 60 m, and 10 m using NRG#40C calibrated three cup anemometer sensors. For its part, wind directions are measured at 120 m, 100 m, 80 m, and 60 m using SP200 calibrated wind vane sensors. It is to be noted that both the wind speed and direction sensors were installed on instrument booms having a boom length of 2.5 m and a bootie height of 0.5 m. Air temperature and relative humidity are observed at 10 m using the NRG#110S temperature sensor, while the atmospheric pressure is measured using a BP200 barometric pressure sensor. All of this data is measured every second and is recorded every 10 minutes using the Nomad II Wind data logger. Daily data files are sent to the Solar and Wind Energy Research Laboratory (SWERL), Thaksin University, Thailand, via the telecommunication system through GPRS mobile SIM package every day. Fig. 4 shows the configuration of the 120 m met tower.

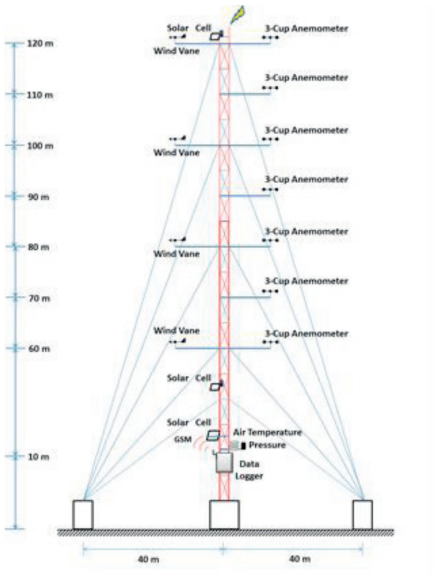

Fig. 4. Configuration of the met tower.

2.3. Wind Flow Modeling

In this work, the wind climate over the study area are estimated using the Wind Alas Analysis and Application Program (WAsP) v9.0.

WAsP, which is based on the linear Jackson-Hunt wind flow model, is the surface wind flow numerical model most used in the wind energy industry and is broadly accepted as a wind resource assessment tool. It was developed by Risø back in the late 1980's as a part of a European Community Program to map the wind resource over Europe. In terms of methodology, WAsP follows a basic wind atlas methodology: it assumes that local observed wind statistics can be corrected for local effects from orography, roughness, and obstacles to generate standardized free flow wind statistics, i.e., a Wind Atlas. The orography, roughness change and obstacle models in WAsP are simplified models for horizontal wind speeds where non-linear effects on winds are not taken into consideration [18]. WAsP translates all input wind data into summary statistics: wind rose and sectorwise wind speed histogram. Finally, the wind speed histograms are fitted by Weibull distributions for computational efficiency.

2.4. Wind Farm Simulations

Near shore wind farms with capacities of 10 MW (which corresponds to the Very Small Power Producer (VSPP) guidelines in Thailand: maximum installed capacity of 10 MW), 30 MW and 90 MW (which corresponds to the Small Power Producer (SPP) guidelines in Thailand: maximum installed capacity of 90 MW) are simulated in order to estimate the annual energy production (AEP) in GWh/year.

In this work, 9 wind farm case studies are evaluated based on three generic wind turbine generators with rated capacities of 3.0 MW, 5.0 MW, and 7.0 MW. For each wind farm case study, the spacing between subsequent wind turbine generators are varied according to the 10DX10D, 12DX12D, and 15DX15D parking criteria for wind farm layouts as presented in Table 1. The geometric layouts of the wind farm case studies are presented in Fig. 5. For its part, the power curves of three generic wind turbine generators are shown in Fig. 6. From Fig. 6, it can be seen that the cut-in wind speeds of both the 3.0 MW and the 5.0 MW turbines is 3.5 m/s, while for the 7.0 MW turbine it is 4 m/s. The cut-out wind speeds for the three turbines is 25 m/s. The hub height of each wind turbine generator is fixed at 90 m. The AEP of each wind farm case study is estimated using WAsP. To this end, a 20 m resolution microscale wind map of the study area is developed using 1-year observed wind climate data, i.e., speed and direction at turbine hub height (90 m), the respective wind farm layout, and respective wind turbine power curve data. Finally, the theoretical capacity factors (TCF) of the wind farm case studies are also estimated using WAsP.

2.5. Wake Effect Model

It is well documented that the flow of wind inside a wind farm is not uniformed. These disturbances are known as wake effects and in addition to causing other problems, they reduce the energy production of the wind farm. In order to reduce these wake effects and consequently to increase the energy production, wind farms layout can be optimized [17]. In this work, the standard Jensen wake model inside WAsP is applied to the wind farm case studies in order to represent wake effects when evaluating their AEP [18].

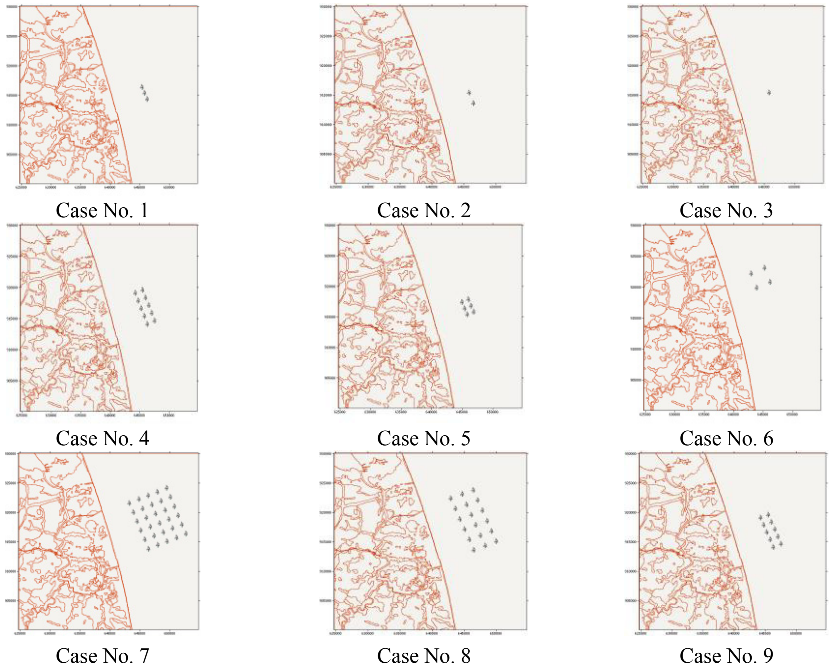

Fig. 5. Layouts of wind turbine generators for the wind farm case studies.

Table 1 Case study wind farm development.

Case		Wind Turbine Generator Capacity (MW)	No. of Wind Turbine Generator	Total Installed Capacity (MW) by Geometric Layout		
				10DX 10D	12DX 12D	15DX 15D
VSPP	C1	3	3	9	9	9
	C2	5	2	10	10	10
	C3	7	1	7	7	7
3 VSPP	C4	3	10	30	30	30
	C5	5	6	30	30	30
	C6	7	4	28	28	28
SPP	C7	3	30	90	90	90
	C8	5	18	90	90	90
	C9	7	12	84	84	84

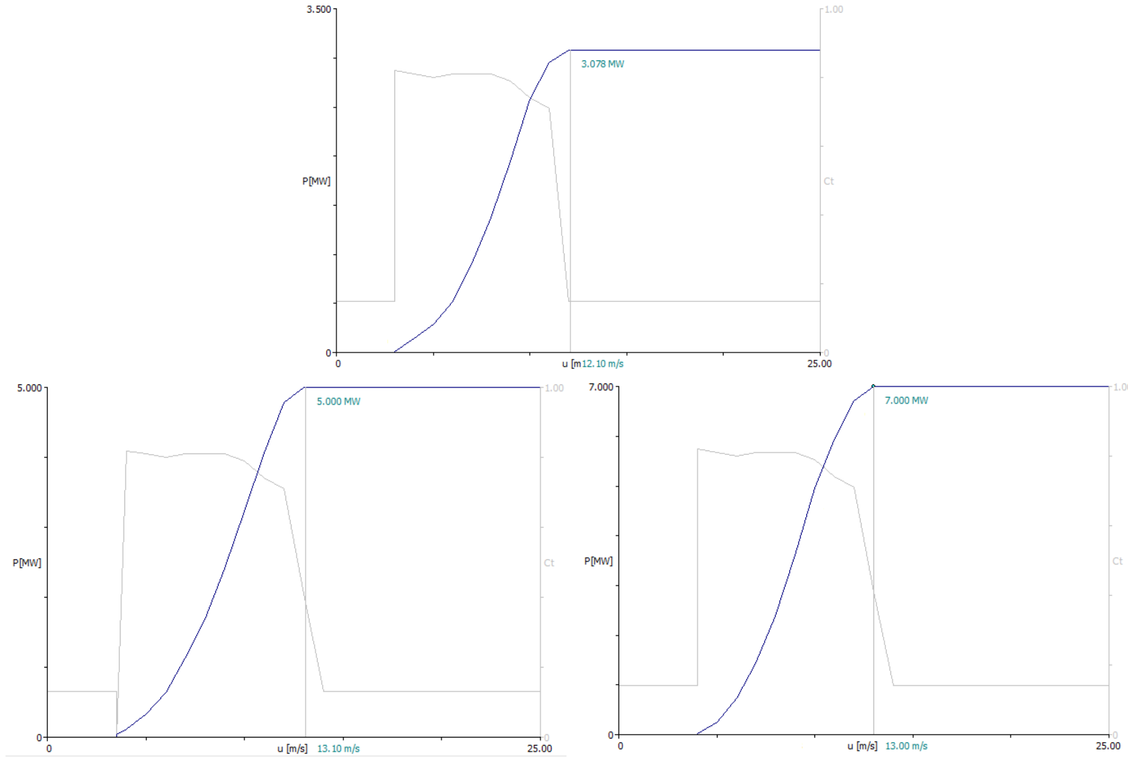

Fig. 6. Power curve of 3 generic models of a wind turbine generator; 3.0 MW (top), 5.0 MW (middle), and 7.0 MW (bottom).

3. Result and discussion

Furthermore, the current tower height is between 80-110 m. Therefore, the observation of wind speed at 80-100 m is satisfaction and comply with the rule of 2/3 observation and extrapolation technique for accuracy data analysis.

For its part, the 20 m resolution microscale wind resource map at 120 m A.G.L. of the study area is shown in Fig. 10. It can be seen from Fig. 10 that the wind regime across the study area is quite uniform: the difference between the maximum and the minimum mean wind speeds is in the rage of 0.03 m/s. The difference in mean wind speeds occurs along the shoreline; this is due to the roughness change between the water and shoreline that affects the microscale wind flow.

Fig. 11 and Fig. 12 show the AEP and wake effects for the 9 wind farm case studies as computed by WAsP, respectively. Results show that the AEP for the 9 wind farm case studies range from approximately 10 to 168 GWh/year. Furthermore, results show that the 15DX15D wind farm layout maximizes the AEP for all wind farm case studies. In this work, wind farm case study no. C7 with its 15DX15D layout produces the maximum AEP at approximately 168 GWh/year, as shown in Fig. 11.

In regards to the wake losses, results show that for the 9 wind farm case studies, they range from approximately 0.03 to 6.71% depending on the geometrical layout of the wind farms, as shown in Fig. 12. As expected, the wake effects diminish as the spacing between wind turbine generators increase as can be seen for wind farm case studies no. 4 to 9. These results show the layout of wind farm is another crucial issue for which careful considerations must be taken into account during the wind farm design phase. However, since the wind turbine generators are spaced further apart in the 15DX15D parking criteria, this leads to the use of longer submarine cables to transport the electricity generated from each wind turbine. Consequently, this results in higher wind farm installation costs. The compromise between maximizing the AEP and minimizing the project investment costs should be taken into account in order to optimize the project's financial economics; however, the optimization of a wind farm's financial economics is out of the scope of this work.

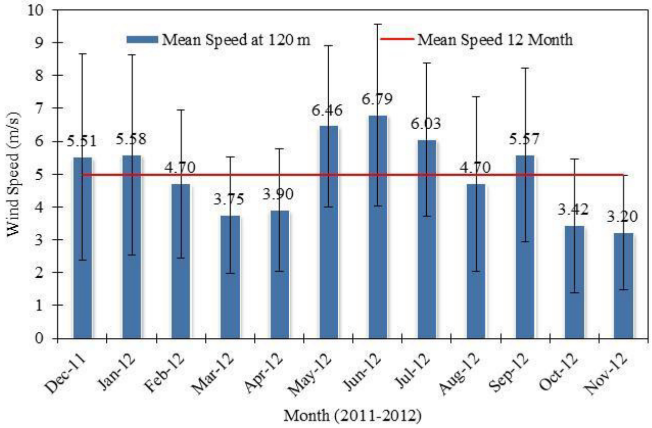

Fig. 7. Annual and monthly mean wind speeds at the met tower site.

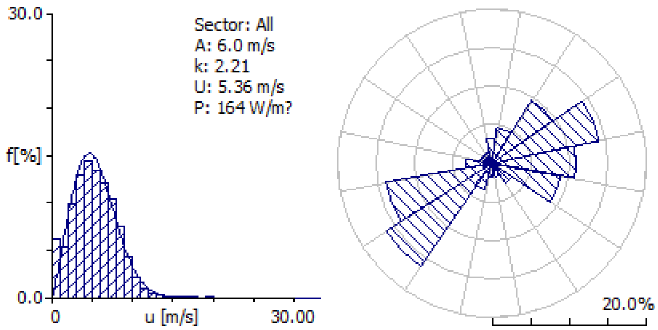

Fig. 8. Weibull distribution and wind rose of 1-year observed wind speed and direction at 120 m A.G.L. in Pakpanang district, Nakhon Si Thammarat province

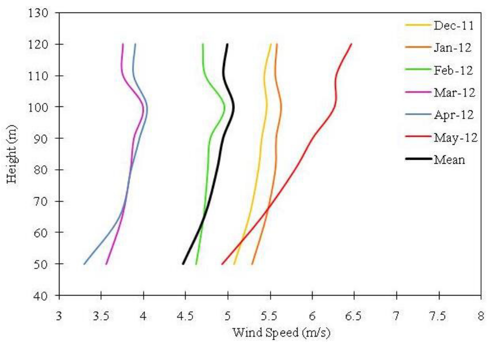

Fig. 9. Vertical profile of monthly mean speeds at Pakpanang district, Nakhon Si Thammarat province.

Another useful parameter to compare the performances between wind farm case studies is the theoretical capacity factor (TCF). The TCF represents an indicator of the wind farm's efficiency in converting wind energy into electricity. Fig. 13 shows that the TCF for the 9 wind farm case studies range from a minimum of 15.1% to a maximum of 22.1%. When comparing the wind farm case studies using the same wind turbine generator (i.e., wind farm case studies no.1, no. 4 and no. 7), results show that the TCF is lower as the number of wind turbine generators increases. This is due to increase in wake effects in the larger wind farms.

As was the case with the geometric layout of the wind turbines to lower the wake effects, a trade-off must be made in regards to the total installed capacity of a wind farm and the project's financial economics. Generally, there is an economy of scale effect which tends to favour larger wind farms. Nowadays, the installed capacity of offshore wind farms that have already been developed in northern Europe are in the range of 100 to 300 MW.

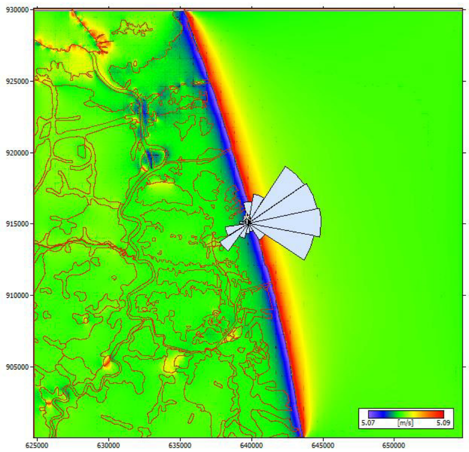

Fig. 10. Microscale wind resource map at 120 m A.G.L. Pakpanang district in Nakhon Si Thammarat province, Thailand.

Currently, the largest offshore project is the Welney project in the Irish Sea with a total installed capacity of 367 MW. In Asia, the first offshore wind farm in China had an installed capacity of 102 MW. Moreover, most offshore wind farm projects that are being developed or that are in the pipeline, especially in the North Sea in Northern Europe, in the U.S.A., or even in Asia (mostly in China), have installed capacities in the range of 300 to 500 MW [19]. Consequently, in terms of near shore or offshore wind farm development, the capacity of wind farm should be ranged between 90 to 300 MW in order to maximize the AEP and to maximize the economics of scale; this generally will optimize the project's financial economics.

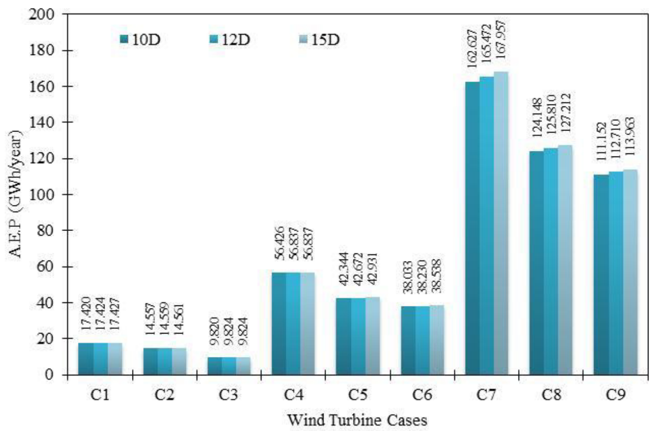

Fig. 11. Annual energy production of 9 cases wind farm in Pakpanang district in Nakhon Si Thammarat province.

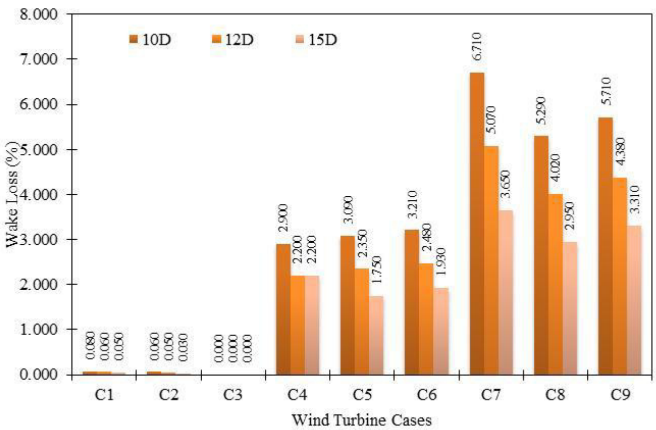

Fig. 12. Wake losses from 9 cases wind farm simulation using WAsP and standard wake model.

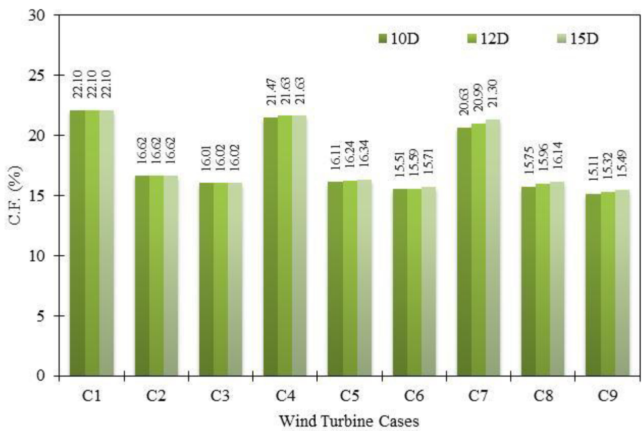

Fig. 13. Theoretical capacity factors of 9 cases wind farm in Pakpanang district in Nakhon Si Thammarat province.

4. Conclusion

The work presented in this paper concerns the micro-siting wind resource assessment and near shore wind farm analysis in Pakpanang district, Nakhon Si Thammarat province, southern Thailand. One year of observed wind speed and wind direction data from a 120 m met tower installed near the shoreline are analyzed in order to investigate the monthly mean wind speeds and dominant wind directions at the site. The observed wind data is used to develop a 20 m resolution microscale map of the study area in order to analyze several configurations of near shore wind farms in the range of 10 to 90 MW.

In order to reach this objective, the annual energy productions (AEP), the wake effects, and the theoretical capacity factors of wind farm configurations (TCF) are estimated using WAsP. Results show that the monthly mean wind speeds at 120 m above ground level are in the range of 3.3 to 5.3 m/s. The dominant wind at the site are from the NEE and SSW directions. In terms of the near shore wind farm analysis, the maximum net AEP is approximately 170 GWh/year (90 MW wind farm scenario), while the corresponding wind farm's wake loss is 3.65%, which corresponds to a 21.3% wind farm TCF.

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